PROVISIONAL TERMS OF REFERENCE

FOR THE

JOINT TECHNICAL COMMITTEE

OF

THE PACIFIC HAKE/WHITING AGREEMENT BETWEEN THE GOVERNMENTS OF THE UNITED STATES OF AMERICA AND CANADA

Joint Technical Committee
16 JANUARY 2014

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List of Terms and Acronyms

Acceptable biological catch (ABC): The Acceptable biological catch is a scientific calculation of the sustainable harvest level of a fishery used historically to set the upper limit for fishery removals by the Pacific Fishery Management Council. It is calculated by applying the estimated (or proxy) harvest rate that produces maximum sustainable yield (*MSY*, see below) to the estimated exploitable stock biomass (the portion of the fish population that can be harvested). For Pacific Hake, the calculation of the acceptable biological catch and application of the 40:10 adjustment is now replaced with the default harvest rate and the Total Allowable Catch.

Advisory Panel (AP): The advisory panel on Pacific Hake/Whiting established by the Agreement.

Agreement ("Treaty"): The Agreement between the government of the United States and the Government of Canada on Pacific Hake/Whiting, signed at Seattle, Washington, on November 21, 2003, and formally established in 2011.

Default harvest rate: The application of F-40 Percent with the 40:10 adjustment. Having considered any advice provided by the Joint Technical Committee, Scientific Review Group or Advisory Panel, the Joint Management Committee may recommend a different harvest rate if the scientific evidence demonstrates that a different rate is necessary to sustain the offshore hake/whiting resource.

Joint Management Committee (JMC): The joint management committee established by the Agreement.

Joint Technical Committee (JTC): The joint technical committee established by the Agreement.

Pacific Fishery Management Council (PFMC): The U.S. organization under which historical stock assessments for Pacific hake were conducted.

Pacific Hake/Whiting ("Pacific Hake"): The stock of *Merluccius productus* located in the offshore waters of the United States and Canada (not including smaller stocks located in Puget Sound and the Strait of Georgia).

Scientific Review Group (SRG): The scientific review group established by the Agreement.

Spawning potential ratio (SPR): A metric of fishing intensity. The ratio of the spawning output per recruit under a given level of fishing to the estimated spawning output per recruit in the absence of fishing. It achieves a value of 1.0 in the absence of fishing and declines toward 0.0 as fishing intensity increases.

F-40 Percent ($F_{40\%}$): The rate of fishing mortality estimated to reduce the spawning potential ratio to 40%.

40:10 Adjustment: an adjustment to the overall total allowable catch that is triggered when the biomass falls below 40% of its average equilibrium level in the absence of fishing. This adjustment reduces the total allowable catch on a straight-line basis from the 40% level such that the total allowable catch would equal zero when the stock is at 10% of its average equilibrium level in the absence of fishing.

Total Allowable Catch (TAC): The maximum fishery removal under the terms of the Agreement.

U.S./Canadian allocation: The division of the total allowable catch of - 73.88% as the United States' share and 26.12% as the Canadian share.

Introduction and Overview

The purpose of this terms of reference is to outline the guidelines and procedures for the stock assessment of Pacific Hake/Whiting (*Merluccius productus*) by the Joint Technical Committee (JTC) established under the 2011 Agreement between the Government of Canada and the Government of the United States of America on Pacific Hake/Whiting (the treaty).

This is the provisional 2014 edition of the terms of reference for the JTC. At the time of writing it is provisional, pending approval by the Joint Management Committee (JMC). This draft document reflects the fact that, prior to November 2011, the stock assessment and stock assessment review for Pacific hake previously fell under the responsibility of the Pacific Fishery Management Council (PFMC) and, for continuity, is generally based on the terms of reference used by the PFMC. As processes evolve under the treaty, it is expected that these terms of reference will also evolve in coming years. Participants should therefore anticipate the need to be flexible and address new issues as they arise.

Under the treaty language, the JTC is tasked to:

1) Propose its terms of reference for stock assessment and review (this document) for approval by the JMC.
2) Develop stock assessment criteria and methods, and design survey methods.
3) Exchange survey information, including information on stock abundance, distribution, and age composition.
4) Exchange and review relevant annual catch and biological data, including information provided by the public.
5) Provide, by no later than February 1 of each year unless otherwise directed by the JMC (February 4, 2014), a stock assessment that includes scientific advice on the annual potential yield of the Pacific hake resource that may be caught for that fishing year, taking into account uncertainties in stock assessment and stock productivity parameters and evaluating the risk of errors in parameter estimates produced in the assessment.
6) Perform other analyses that may be referred to it by the Scientific Review Group (SRG) and the JMC.

JTC Responsibilities

The JTC is responsible for conducting a complete and technically sound stock assessment that conforms to accepted standards of quality and in accordance with these terms of reference. The products of the JTC will be a draft stock assessment document to be reviewed by the SRG and a final version that follows the outline specified in Appendix A below.

Terms of Reference for the JTC

The goals and objectives for the stock assessment and review process are to:

a) Ensure that the Pacific Hake stock assessment represents the "best available" scientific information and facilitate the use of this information by the JMC and Advisory Panel (AP). In particular, provide information that will allow the JMC to set annual catch limits.
b) Meet the mandates of the Pacific Hake treaty and other legal requirements.
c) Follow a detailed calendar and explicit responsibilities for all participants to produce required outcomes and reports.
d) Provide for a review of the stock assessment methods by the SRG.
e) Use assessment and review resources effectively and efficiently.
f) Increase understanding of the Pacific Hake stock assessment and review process.
g) Identify research needed to improve data collection, surveys, assessments, reviews, and fishery management in the future.

In order to facilitate peer review, the JTC should carry out its work according to these terms of reference. Generally, in the assessment document the JTC should discuss all data sources, identify the ones being used in the assessment, and provide the rationale for data sources being excluded. The JTC should coordinate early in the process with data stewards in both countries to ensure timely delivery of data required. The JTC is also encouraged to organize independent meetings with industry and interested parties to discuss issues, questions, and data. Barring exceptional circumstances, all JTC members should attend the stock assessment review meeting. The JTC must consider and respond to research recommendations of prior review meetings, and must make a good faith effort to address the issues raised in those reports, to the extent practicable.

The JTC is responsible for preparing two versions of the stock assessment document:

1) A draft document for peer review during the stock assessment review with the SRG.
2) A final document for distribution to the JMC and AP reflecting the outcome of the stock assessment review for use in discussions regarding catch advice.

The JTC is responsible for bringing data in digital format and model files to the review meeting so that they can be analyzed on site. The JTC should have several models ready to present to the SRG and be prepared to discuss the merits of each. The JTC also should identify a candidate base model, fully-developed and well-documented in the draft assessment, for the stock assessment review meeting.

The JTC should provide a draft assessment document to the SRG, JMC and AP chairs two weeks prior to the stock assessment review meeting to allow timely review of the draft assessment (See appendix D). The draft assessment document should include all elements listed in Appendix A except for the: 1) population abundance tables, 2) point-by-point responses to current SRG recommendations, and 3) acknowledgements. If the draft assessment is judged complete, the SRG will distribute the draft assessment and relevant supporting materials to the rest of the SRG, the JMC and the Advisory panel. It is the JTC's responsibility to make sure the document is complete and complies with these terms of reference.

The JTC and the SRG may disagree on technical issues regarding an assessment, and a complete final stock assessment document must include a point-by-point response of the JTC to each of the SRG's recommendations. The final version must be reviewed by the SRG prior to being submitted to the JMC and AP. This review is limited to editorial issues, verifying that the required elements are included according to the terms of reference, and confirming that the document adequately reflects the discussions and decisions made during the stock assessment review meeting. The final version of the assessment document should be provided to the JMC within one week of the end of the stock assessment review meeting.

Electronic versions of final assessment documents, parameter files, data files, and key output files will be made available to all committees and interested parties. Copies of these files will also be included in a stock assessment archives maintained by the U.S. National Marine Fisheries Service and Fisheries and Oceans Canada.

Appendix A: Outline for Stock Assessment Documents

In this outline, the term "stock assessment" includes activities, analyses and reports, beginning with data collection and continuing through to scientific recommendations for the fishery. Stock assessments provide the fundamental basis for management decisions on fishery harvests. To best serve that purpose, stock assessments should attempt to identify and quantify major uncertainties, balance realism and parsimony and make best use of the available data.

This is an outline of items that should be included in the stock assessment report for Pacific Hake. It is a working document meant to provide the JTC with flexible guidelines about how to best organize and communicate their work. Items with asterisks (*) are optional for draft assessment documents prepared for stock assessment review but should be included in the final document. In the interest of clarity, stock assessment authors and reviewers are encouraged to use the same organization and section names as in the outline. However, in the interest of brevity, sections that have been described in previous stock assessment documents and remain unchanged in the most recent stock assessment should be briefly described with a reference to details in previous stock assessment documents. It is important that complete time series of catch, abundance, harvest rates, recruitment and other key quantities be presented in tabular form to facilitate full understanding and follow-up analyses.

1. <u>Title page and list of preparers</u> – the names and affiliations of the stock assessment team (including the JTC and any other contributors) either alphabetically or as first and secondary authors.

2. <u>Executive Summary</u> (see template in Appendix B and example in Appendix C).

3. <u>Introduction</u>
    - 3.1. Scientific name, distribution, the basis for the choice of stock structure, including regional differences in life history or other biological characteristics that should form the basis of management units.
    - 3.2. A discussion of new understandings of ecosystem considerations.
    - 3.3. A map depicting the scope of the assessment and identifying boundaries for fisheries or data collection strata.
    - 3.4. Important features of life history that affect management (e.g., migration, sexual dimorphism, bathymetric demography).
    - 3.5. Important features of current fishery and relevant history of fishery.
    - 3.6. Reference to management history (e.g., changes in mesh sizes, trip limits, or other management actions that may have significantly altered selection, catch rates, or discards).
    - 3.7. Management performance – a table or tables comparing historical management limits and targets with fishery removals for each area and year.

4. <u>Assessment</u>
    - 4.1. Data
        - 4.1.1. Historical catch estimates by year and fishery, catch-at-age, weight-at-age, abundance indices, data used to estimate biological parameters (e.g., growth rates, maturity schedules, and natural mortality) with coefficients of variation (CVs) or variances if available. Include complete tables and figures and date of

extraction.

- 4.1.2. Sample size information for length and age composition data by area, year, gear, market category, etc., including both the number of trips and fish sampled.
- 4.1.3. All data sources that are used in the assessment and rationale for data sources that are excluded.

4.2. History of modeling approaches used for this stock.

4.3. Changes between current and previous assessment models.

- 4.3.1. Response to stock assessment review meeting recommendations from the most recent assessment.

4.4. Model description

- 4.4.1. Complete description of any new modeling approaches.
- 4.4.2. Definitions of fleets and areas.
- 4.4.3. Analysis software used with last revision date.
- 4.4.4. List and description of all likelihood components in the model.
- 4.4.5. Priors and/or constraints on parameters, selectivity assumptions, natural mortality, treatment of age reading bias and/or imprecision, and other fixed parameters.
- 4.4.6. Description of stock-recruitment constraints or components.
- 4.4.7. Description of how the first year that is included in the model was selected and how the population state at the time is defined.
- 4.4.8. Critical assumptions and potential consequences of assumption failures.

5. Model selection and evaluation

- 5.1. Evidence of search for balance between model realism and parsimony.
- 5.2. Comparison of key model assumptions, include comparisons based on nested models (e.g., asymptotic vs. domed selectivities, constant vs. time-varying selectivities).
- 5.3. Summary of alternate model configurations that were tried but rejected.
- 5.4. Residual analysis for the base-run configuration (e.g., residual plots, time series plots of observed and predicted values, or other approaches).
- 5.5. Convergence status and convergence criteria for the base-run model.
- 5.6. Evidence of search for global best estimates.

6. *Point-by-point response to the most recent SRG recommendations

7. Base model results

- 7.1. Table listing all explicit parameters in the stock assessment model used for the base model, its purpose (e.g., recruitment parameter, selectivity parameter) and whether or not the parameter was actually estimated in the stock assessment model.
- 7.2. Population numbers at age by year and, if applicable, by sex.
- 7.3. Time-series of total, 1+, summary, and spawning biomass (and/or spawning output), depletion relative to B0, recruitment and fishing mortality or exploitation rate estimates (table and figures).
- 7.4. Selectivity estimates.
- 7.5. Stock-recruitment relationship.
- 7.6. Clear description of units for all outputs.
- 7.7. Qualitative evaluation of credibility of parameter estimates.

8. Uncertainty and sensitivity analyses. The best approach for describing uncertainty may depend on the specific situation; important factors to consider include:

8.1. Uncertainty in parameter estimates and in derived outputs of the model (e.g., bootstrap, asymptotic methods, Bayesian integration).
8.2. Likelihood profile or posterior profile for the base-run (or proposed base-run model for a draft assessment undergoing review) configuration over one or more key parameters (e.g., natural mortality, steepness of the stock-recruitment function) to investigate consistency among input data sources.
8.3. Sensitivity to dataset choice and weighting of data and likelihood components.
8.4. Consideration of recent patterns in recruitment.
8.5. Sensitivity to assumptions about model structure.
8.6. Retrospective analyses, where the model is fitted to a series of shortened input data sets, with the most recent years of input data being dropped, and current results compared with historical assessments.
8.7. If a range of sensitivity runs is used to characterize uncertainty it is important to attempt to provide some qualitative or quantitative information about the relative probability of each.

9. <u>Reference points needed to produce default harvest rate calculations</u>
9.1. Unexploited equilibrium spawning stock biomass (or spawning output, if spawning output is other than linearly related to spawning biomass), summary age biomass, and recruitment.
9.2. Reference points based on SB40% (spawning biomass and/or output, SPR, exploitation rate, equilibrium yield).
9.3. Reference points based on F40% (spawning biomass and/or output, SPR, exploitation rate, equilibrium yield).
9.4. Reference points based on MSY (if estimated; spawning biomass and/or output, SPR, exploitation rate, equilibrium yield).
9.5. Equilibrium yield curve showing various BMSY proxies (see Appendix C).

10. <u>Harvest projections and decision tables</u>
10.1. Decision tables should follow the format of the example Executive Summary given in Appendix C of this document, in which the columns represent the states of nature and the rows the management alternatives. Management alternatives should represent the sequence of catches obtained by applying the default harvest policy to each state of nature and/or other alternatives requested by the JMC.
10.2. Information presented should include biomass, stock depletion, and yield projections of potential TAC values for three years into the future, beginning with the current year.
10.3. Harvest projections and decision tables should cover the plausible range of uncertainty about current biomass and a range of harvest levels. Harvest levels should include calculation of the TAC based on the default harvest rate. Additionally, TAC calculations based on FMSY and/or other options, as requested by the JMC or on the basis of analyses provided by the JTC may be included. States of nature described in the decision table will be drawn from a probability distribution which describes the pattern of uncertainty regarding the status of the stock and the consequences of alternative future management actions. Where alternatives are not formally associated with a probability distribution, the assessment should provide subjective probabilities for each alternative.

11. <u>Research needs (prioritized)</u>

12. Acknowledgments

13. Literature cited

14. Appendices
    14.1. A list of definitions and acronyms for technical terms used in the document.
    14.2. Complete input files for the stock assessment program(s).

Appendix B: Template for Executive Summary Prepared by JTC

Stock: Spatial extent of the assessment including an evaluation of any potential biological basis for regional management.

Catches: Historical and current levels, including a table for last 10 years and a graph with the entire time-series.

Data and assessment: Date of last assessment, type of assessment model(s), data available, new information, and information lacking.

Stock biomass: Historical and current biomass estimates, as well as relative depletion estimates. This section should include a description of uncertainty, and tables of biomass and depletion for the last 10 years and graphs with the entire available time-series.

Recruitment: Historical and current estimates, this section should include a description of uncertainty and a table for the most recent 10 years and a graph with the entire time-series.

Reference points: Management targets and definition of overfishing, including the harvest rate that brings the stock to equilibrium at $SB_{40\%}$ and the equilibrium stock size that results from fishing at the default harvest rate. Include a summary table that compares estimated spawning biomass, exploitation rate and yield based on reference points.

Exploitation status: Exploitation rates (i.e., total catch divided by exploitable biomass, or the annual SPR harvest rate). This section should include a table with the last 10 years of estimates and a graph with the entire time-series.

Management performance: A table or tables comparing total fishery removals with historical management limits and targets during the most recent 10 years. This section should include a phase-plot showing the trend in fishing mortality relative to the target (y-axis) plotted against the trend in biomass relative to the target (x-axis).

Unresolved problems and major uncertainties: A discussion of major sources of uncertainty and possible sources of bias in the stock assessment results. This should include a discussion of major information gaps.

Forecasts and Decision table: Three-year projections of spawning biomass, and stock depletion and exploitation rates for management alternatives.

Research and data needs: Prioritize potential future research that may appreciably reduce the uncertainty in future stock assessments and management.

Appendix C: Executive Summary from the 2013 Stock Assessment

Stock

This assessment reports the status of the coastal Pacific hake (or Pacific whiting, *Merluccius productus*) resource off the west coast of the United States and Canada. This stock exhibits seasonal migratory behavior, ranging from offshore and generally southern waters during the winter spawning season to coastal areas between northern California and northern British Columbia during the spring, summer and fall when the fishery is conducted. In years with warmer water temperatures the stock tends to move farther to the North during the summer and older hake tend to migrate farther than younger fish in all years. Separate, and much smaller, populations of hake occurring in the major inlets of the northeast Pacific Ocean, including the Strait of Georgia, Puget Sound, and the Gulf of California, are not included in this analysis.

Catches

Coast-wide fishery landings of Pacific hake averaged 222,000 mt from 1966 to 2012, with a low of 90,000 mt in 1980 and a peak of 363,000 mt in 2005. Prior to 1966 the total removals were negligible relative to the modern fishery. The fishery in U.S. waters has averaged 166,000 mt, or 74.7% of the average total landings over the time series, with the catch from Canadian waters averaging 56,000 mt. During the fishery's first 25 years, the majority of removals were from foreign or joint-venture fisheries. In this stock assessment, the terms catch and landings are used interchangeably; estimates of discard within the target fishery are included, but discarding of Pacific hake in non-target fisheries is not. Discard from all fisheries is estimated to be less than 1% of landings and therefore is likely to be negligible with regard to the population dynamics.

Recent coast-wide landings from 2008–2012 have been above the long term average, at 243,000 mt. Landings between 2001 and 2008 were predominantly comprised of fish from the very large 1999 year class, with the cumulative removal from that cohort exceeding an estimated 1.2 million mt. In 2008, the fishery began harvesting considerable numbers of the then emergent 2005 year class. Catches in 2009 were again dominated by the 2005 year class with some contribution from an emergent 2006 year class and relatively small numbers of the 1999 cohort. The 2010 and 2011 fisheries encountered very large numbers of the 2008 year-class, while continuing to see some of the 2005 and 2006 year-classes as well as a small proportion of the 1999 year class. In 2012, U.S. fisheries caught mostly 2 and 4-year old fish from the 2008 and 2010 year classes, while the Canadian fisheries encountered older fish from the 2005, 2006, and 2008 year classes. A considerable number of 2-year old fish were caught by the U.S. at-sea fleet later in the year.

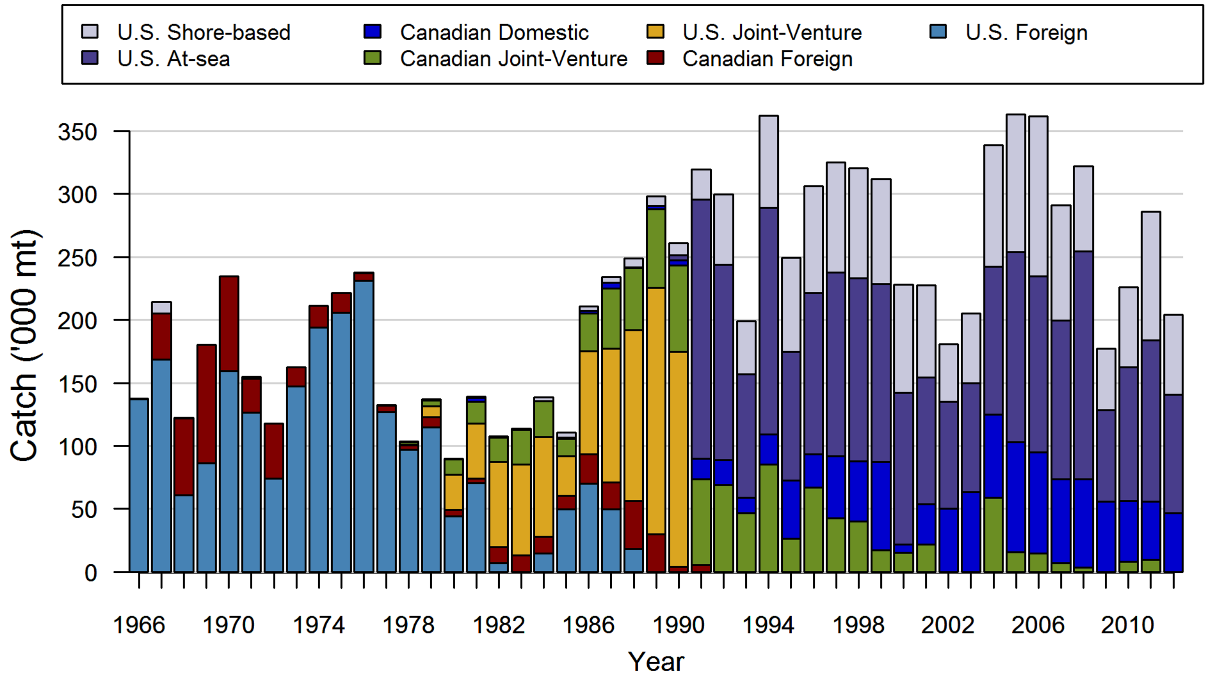

Figure a. Total Pacific hake catch used in the assessment by sector, 1966-2012. Tribal catches are included.

Table a. Recent commercial fishery catch (1,000's mt). Tribal catches are included where applicable.

Year	US at-sea	US shore-based	US total	Canadian joint-venture	Canadian domestic	Canadian total	Total
2003	87	55	142	0	63	63	205
2004	117	97	214	59	66	125	339
2005	151	109	260	16	87	103	363
2006	140	127	267	14	80	95	362
2007	126	91	218	7	67	73	291
2008	181	68	248	4	70	74	322
2009	72	49	122	0	56	56	177
2010	106	64	170	8	48	56	217
2011	128	102	230	10	46	56	286
2012	94	63	157	0	47	47	204

Data and assessment

Data have been updated for the 2013 assessment with the addition of new ages into the 2011 age distribution, the addition of a new age distribution from the 2012 fishery and acoustic survey, and addition of the 2012 acoustic survey biomass estimate to the abundance index.

This assessment reports a single base-case model representing the collective work of the Joint Technical Committee (JTC), and depends primarily upon nine years of an acoustic survey biomass index as well as catches for information on the scale of the current hake stock. The 2011 survey index value is the lowest in the time-series, and the 2012 index is more than 2.5 times greater. The age-composition data from the aggregated fisheries (1975-2012) and the acoustic survey contribute to the assessment model's ability to resolve strong and weak cohorts. Both sources indicate a strong 2008 cohort in the 2011 and 2012 data, and a strong 2010 cohort in the 2012 data, which may partially explain the recent increase in the survey index.

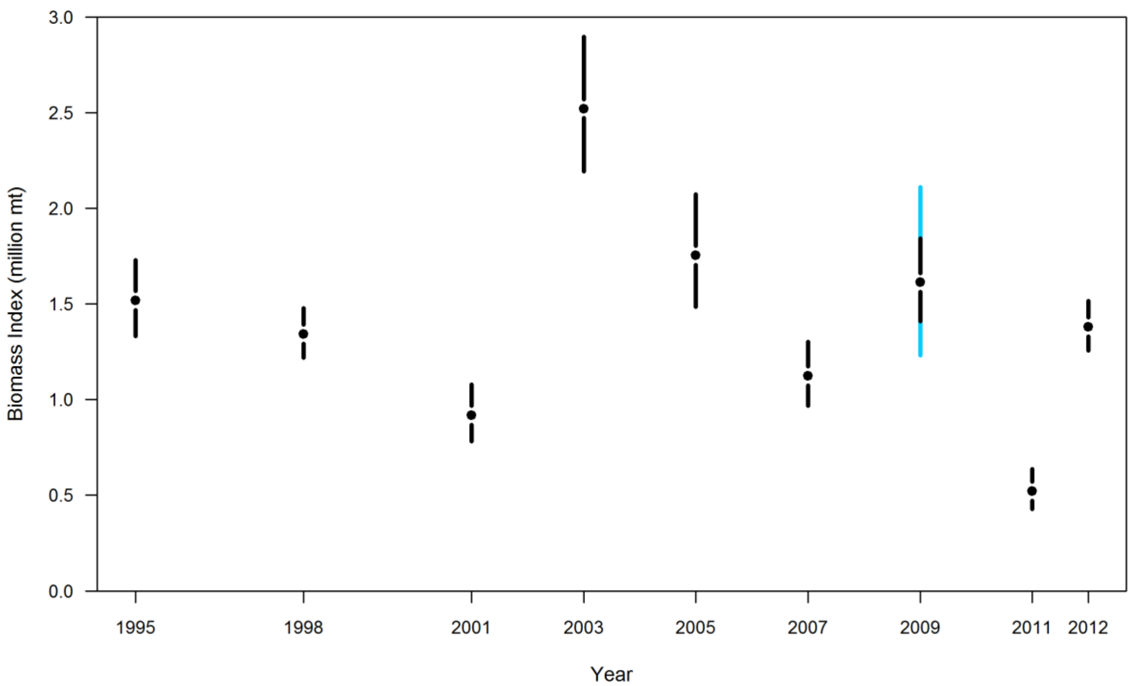

Figure b. Acoustic survey biomass index (millions of metric tons). Approximate 95% confidence intervals are based on only sampling variability (1995–2007, 2011–2012) in addition to squid/hake apportionment uncertainty (2009, in blue).

The assessment uses Bayesian methods to incorporate prior information on two key parameters (natural mortality, *M*, and steepness of the stock-recruit relationship, *h*) and integrate over parameter uncertainty to provide results that can be probabilistically interpreted. The exploration of uncertainty is not limited to parameter uncertainty as structural uncertainty is investigated through sensitivity analyses.

Stock biomass

The base-case stock assessment model indicates that Pacific hake female spawning biomass was below the unfished equilibrium in the 1960s and 1970s. The stock is estimated to have increased rapidly after two or more large recruitments in the early 1980s, and then declined steadily after a peak in the mid- to late-1980s to a low in 2000. This long period of decline was followed by a brief increase to a peak in 2003 (a median female spawning biomass estimate of 1.34 million mt in the SS model) as the large 1999 year class matured. The stock is then estimated to have declined with the aging 1999 year class to a female spawning biomass time-series low of 0.42 million mt in 2009. This recent decline is similar to that estimated in the 2012 assessment, but at a slightly greater absolute value. The current (2013) median posterior spawning biomass is estimated to be 72.3% of the estimated unfished equilibrium level (SB_0) with 95% posterior credibility intervals ranging from 34.7% to 159.7%. The estimate of 2013 female spawning biomass is 1.50 million mt, which is more than double the projected spawning biomass from the 2012 assessment (0.64 million mt). The difference in projected biomass is largely driven by increases in the estimated size of the 2008 and 2010 year classes.

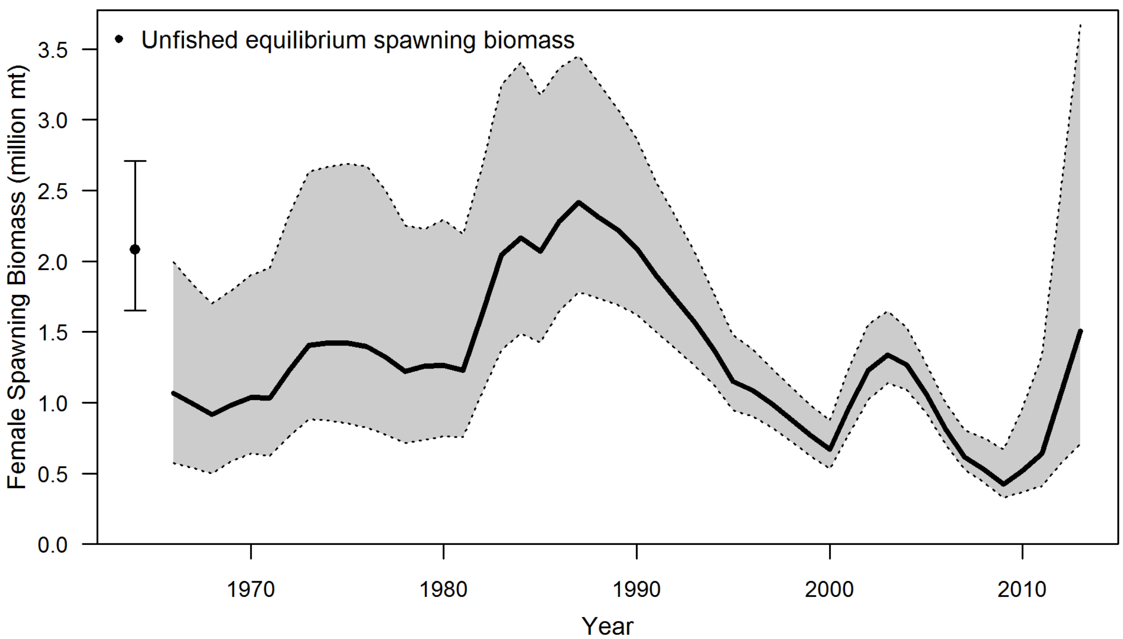

Figure c. Median of the posterior distribution for female spawning biomass through 2013 (solid line) with 95% posterior credibility intervals (shaded area).

Table b. Recent trends in estimated Pacific hake female spawning biomass (million mt) and depletion level relative to estimated unfished equilibrium.

Year	Spawning biomass (mt)			Depletion (SB_t/SB_0)		
	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2004	1.093	1.268	1.530	0.475	0.605	0.769
2005	0.929	1.064	1.277	0.401	0.508	0.640
2006	0.705	0.811	1.000	0.307	0.390	0.491
2007	0.527	0.617	0.808	0.236	0.297	0.384
2008	0.436	0.529	0.751	0.199	0.255	0.345
2009	0.327	0.424	0.670	0.152	0.204	0.303
2010	0.371	0.520	0.964	0.172	0.255	0.418
2011	0.409	0.642	1.333	0.194	0.315	0.579
2012	0.575	1.078	2.542	0.275	0.516	1.109
2013	0.709	1.504	3.676	0.347	0.723	1.597

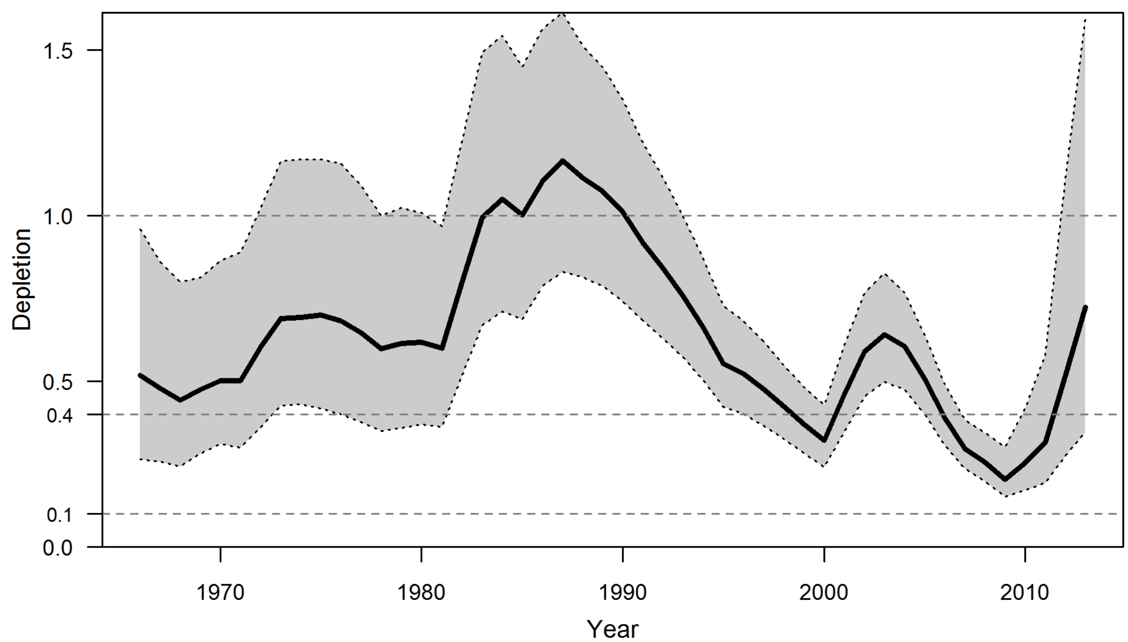

Figure d. Median (solid line) of the posterior distribution for spawning depletion (*SB_t/SB_0*) through 2013 with 95% posterior credibility intervals (shaded area). Dashed horizontal lines show 10%, 40% and 100% depletion levels.

Recruitment

Recruitment is highly variable for Pacific hake. Large year classes in 1980, 1984, and 1999 have been a major component of the fishery in the 1980's and early 1990's, and the early 2000's. Recently, strong year classes are estimated in 2008 and 2010, although the uncertainty about 2010 year class strength is large given the limited exposure to fisheries. In the last decade, estimated recruitment has been at some of the lowest values in the time-series as well some of the highest.

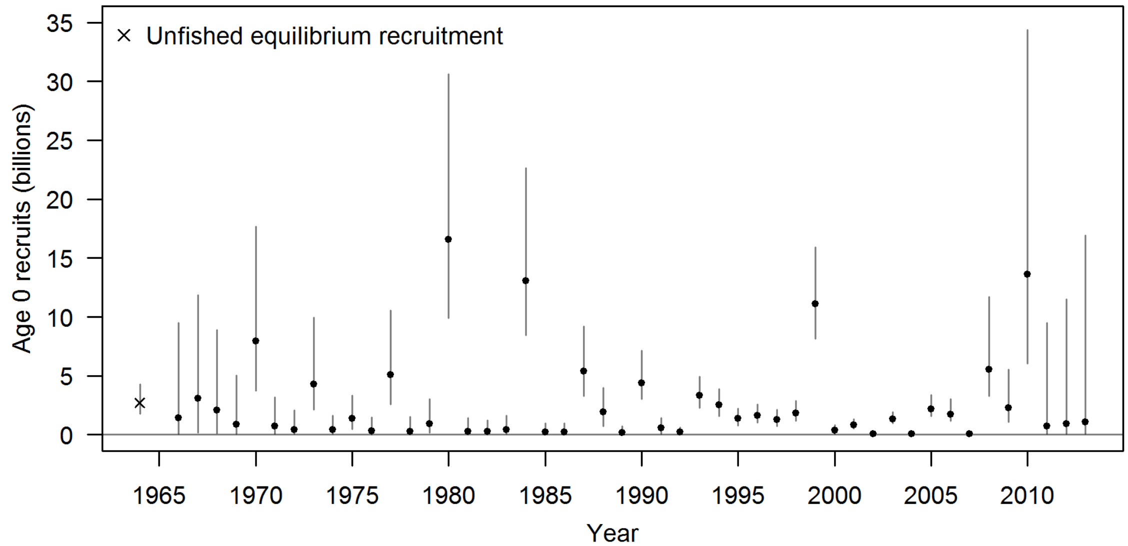

Figure e. Medians (solid circles) of the posterior distribution for recruitment (billions of age-0) with 95% posterior credibility intervals (gray lines). Unfished equilibrium recruitment is shown as an X.

Table c. Estimates of recent Pacific hake recruitment (billions of age-0).

Year	2.5th percentile	Median	97.5th percentile
2004	0.012	0.069	0.228
2005	1.557	2.172	3.379
2006	1.151	1.721	3.048
2007	0.017	0.088	0.295
2008	3.288	5.526	11.720
2009	1.088	2.269	5.519
2010	6.037	13.606	34.396
2011	0.060	0.737	9.509
2012	0.054	0.916	11.500
2013	0.054	1.061	16.926

Exploitation status

Fishing intensity on the Pacific hake stock is estimated to have been below the $F_{40\%}$ target until 2007. The base-case model estimates of prior fishing intensity indicate that the target was likely exceeded in three of the last five years. (It should be noted, however, that the harvest in those years did not exceed the catch limits that were specified, based on the best available science at the time.) The exploitation fraction does not necessarily correspond to fishing intensity because fishing intensity accounts for the age-structure of the population. For example, the fishing intensity remained nearly constant and above target from 2010 to 2011. However, the exploitation fraction declined in these years because of many estimated 1 year old fish.

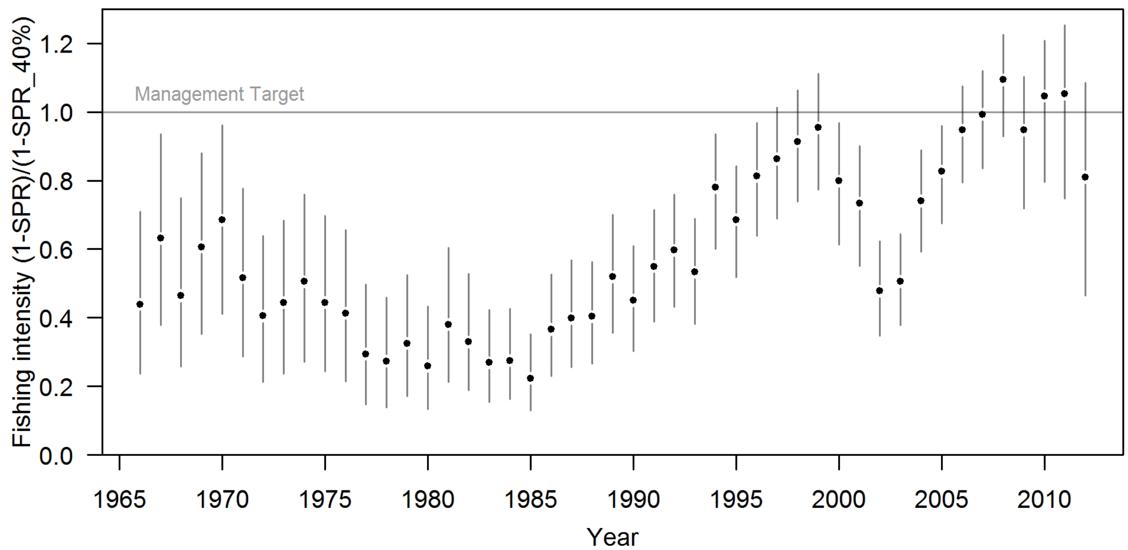

Figure f. Trend in median fishing intensity (relative to the SPR management target) through 2012 with 95% posterior credibility intervals. The management target define in the Agreement is shown as a horizontal line at 1.0.

Table d. Recent trend in fishing intensity (relative spawning potential ratio; (1-SPR)/(1-SPR$_{40\%}$)) and exploitation rate (catch divided by vulnerable biomass).

	Fishing intensity			Exploitation fraction		
Year	2.5th percentile	Median	97.5th percentile	2.5th percentile	Median	97.5th percentile
2003	37.8%	50.6%	64.4%	5.1%	6.3%	7.5%
2004	59.2%	74.1%	88.9%	10.6%	12.8%	14.8%
2005	67.5%	82.7%	96.0%	15.6%	18.7%	21.4%
2006	79.4%	94.7%	107.6%	18.3%	22.7%	26.0%
2007	83.5%	99.3%	112.0%	21.2%	27.5%	32.2%
2008	92.8%	109.4%	122.5%	20.8%	29.2%	35.2%
2009	71.7%	94.7%	110.3%	11.7%	18.4%	23.8%
2010	79.6%	104.7%	120.9%	18.2%	30.7%	42.3%
2011	74.8%	105.2%	125.3%	10.5%	21.5%	33.5%
2012	46.4%	81.0%	108.5%	6.3%	14.5%	26.4%

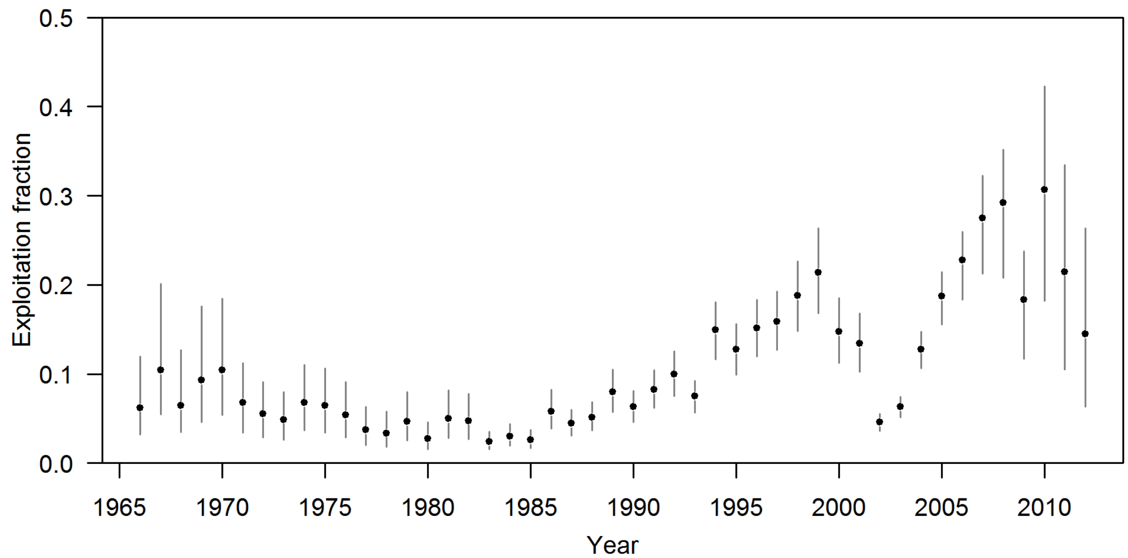

Figure g. Trend in median exploitation fraction through 2012 with 95% posterior credibility intervals.

Management Performance

Since implementation of the Magnuson-Stevens Fishery Conservation and Management Act in the U.S. and the declaration of a 200 mile fishery conservation zone in both countries in the late 1970s, annual quotas (or catch targets) have been used to limit the catch of Pacific hake in both zones by foreign and domestic fisheries. During the 1990s, however, disagreement between the U.S. and Canada on the division of the total catch led to quota overruns; 1991-1992 quotas summed to 128% of the limit and overruns averaged 114% from 1991-1999. Since 1999, catch targets have been determined using an $F_{40\%}$ default harvest rate with a 40:10 control rule (the default harvest policy) that decreases the catch linearly from a depletion of 40% to a depletion of 10%. Further considerations have often resulted in catch targets to be set lower than the recommended catch limit. The Agreement between the United States and Canada, establishes U.S. and Canadian shares of the coast-wide allowable biological catch at 73.88% and 26.12%, respectively, and this distribution has been adhered to since ratification of the Agreement.

Total catches last exceeded the coastwide catch target in 2002, when landings were 112% of the catch target. Over the last ten years, the average utilization has been 87%. From 2009 to 2012 much of the U.S. tribal allocation remained uncaught and Canadian catches have also been below the limit even though in retrospect the target harvest rate was surpassed in some years. The exploitation history in terms of both the biomass and *F*-target reference points, portrayed graphically via a phase-plot in Figure h, shows that historically the fishing intensity has been low and the biomass has been high. Recently, the estimated depletion level has been below 40% and the fishing intensity high, until 2012 when fishing intensity was below target and depletion was above 40%. Uncertainty is the 2012 estimates of fishing intensity and depletion show a 9% joint probability of being above the target fishing intensity and below 40% depletion.

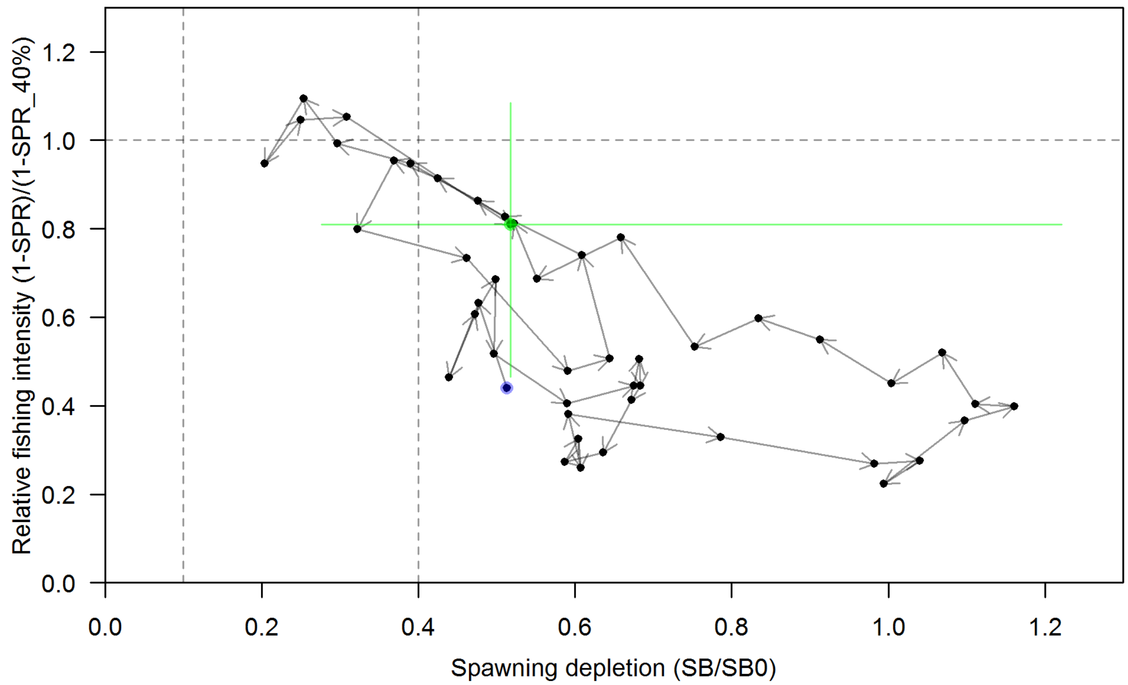

Figure h. Temporal pattern (phase plot) of posterior median fishing intensity vs. posterior median depletion through 2012. The blue circle indicates 1966 and the green circle denotes 2012. Green bars indicatethe 95% posterior credibility intervals along both axes. Arrows indicate the temporal progression of years and the dashed lines indicate the fishing intensity target (vertical) and the 40:10 control rule limits (vertical, 10% and 40%).

Table e: Recent trends in Pacific hake landings and management decisions.

Year	Total Landings (mt)	Coast-wide (US+Canada) catch target (mt)
2003	205,177	228,000
2004	338,654	501,073
2005	363,157	364,197
2006	361,761	364,842
2007	291,129	328,358
2008	322,145	364,842
2009	177,459	184,000
2010	226,202	262,500
2011	286,055	393,751
2012	204,040	251,809

Reference points

The estimated unfished equilibrium spawning biomass estimate was 2,081 thousand mt, which is 10% greater than the estimate reported in the 2012 stock assessment. The 95% posterior credibility interval ranges from 1,653 to 2,709 thousand mt and encompasses the estimate from the 2012 assessment. The spawning biomass that is 40% of the unfished equilibrium spawning biomass ($SB_{40\%}$) is estimated to be 833 thousand mt, which is slightly larger than the equilibrium spawning biomass implied by the $F_{40\%}$ default harvest rate target, 36% of SB_0 (744 thousand mt). *MSY* is estimated to occur at 24% of SB_0 (500 thousand mt) with a yield of 357 thousand mt; only slightly higher than the equilibrium yield at the biomass target ($SB_{40\%}$), 328 thousand mt, and at the $F_{40\%}$ target, 337 thousand mt. The full set of reference points, with posterior credibility intervals for the base case is reported in Table f.

Table f.. Summary of Pacific hake reference points for the base-case model.

Quantity	2.5th percentile	Median	97.5th percentile
Unfished female *SB* (SB_0, thousand mt)	1,653	2,081	2,709
Unfished recruitment (R_0, billions)	1.761	2.687	4.303
Reference points based on $F_{40\%}$			
Female spawning biomass ($SB_{F40\%}$ thousand mt)	556	744	942
$SPR_{MSY\text{-}proxy}$	–	40%	–
Exploitation fraction corresponding to SPR	18.4%	21.8%	25.9%
Yield at $SB_{F40\%}$ (thousand mt)	243	337	479
Reference points based on $SB_{40\%}$			
Female spawning biomass ($SB_{40\%}$ thousand mt)	661	833	1,084
$SPR_{SB40\%}$	40.6	43.2	51.4
Exploitation fraction resulting in $SB_{40\%}$	14.4%	19.2%	23.3%
Yield at $SB_{40\%}$ (thousand mt)	238	328	469
Reference points based on estimated MSY			
Female spawning biomass (SB_{MSY} thousand mt)	328	500	840
SPR_{MSY}	18.3%	28.2%	46.5%
Exploitation fraction corresponding to SPR_{MSY}	17.6%	34.5%	59.5%
MSY (thousand mt)	248	357	524

Unresolved problems and major uncertainties

Measures of uncertainty in this assessment underestimate the true uncertainty in current stock status and future projections because they do not account for alternative structural models for hake population dynamics and fishery processes (e.g., selectivity), the effects of data-weighting schemes, and the scientific basis for prior probability distribution choices.

The JTC investigated a broad range of alternative models, and we present a subset of key sensitivity analyses in the main document. A major source of uncertainty in the 2013 status and target catch is in the estimate of the size of the 2010 year class. The posterior distribution of derived parameters from the base model encompasses the median estimates of most sensitivity models.

Pacific hake displays the highest degree of recruitment variability of any west coast groundfish stock, resulting in large and rapid changes in stock biomass. This volatility, coupled with a dynamic fishery, which potentially targets strong cohorts resulting in time-varying selectivity, and little data to inform incoming recruitment until the cohort is age 2 or greater, will, in most circumstances, continue to result in highly uncertain estimates of current stock status and even less-certain projections of future stock trajectory. Uncertainty in this assessment is largely a function of the potentially large 2010 year class being observed once in the acoustic survey and twice in the fishery, although with low and uncertain selectivity. The supplemental acoustic survey performed in 2012 helped reduce the uncertainty of the strength of this year class, which is an expected result of increasing the survey frequency. However, with recruitment being a main source of uncertainty in the projections and the survey not quantifying hake until they are 2 years old, short term forecasts are very uncertain.

At the direction of the JMC, the JTC developed a Management Strategy Evaluation (MSE) in 2012 to explore the basic performance of the default harvest policy in the context of annual vs. biennial surveys. The results of these explorations showed that biomass levels and average catch are variable, mainly because of the high recruitment variability seen with Pacific hake coupled with potentially large stock assessment estimation biases. Even though the Pacific hake fishery is relatively data-rich, with a directed fishery-independent survey program, substantial biological sampling for both commercial fisheries and the acoustic survey, and reliable estimates of catch, the data are less informative about incoming recruitment which is partially responsible for large differences between the simulated abundance and the estimated abundance.

The MSE simulations show two main results. First, the current $F_{40\%}$-40:10 management strategy with perfect knowledge of current biomass resulted in a median long-term average depletion of less than 30%. Second, there was little difference in median values between strategies involving annual and biennial surveys. At the present time, we consider these conclusions preliminary because our simulations involved a limited range of uncertain processes that are known or suspected to occur for Pacific hake. For example, the structure and assumptions of the stock assessment model used in the annual the assessment-management cycle matched the assumptions of the operating model used to generate stock dynamics and assessment data. Such a match typically underepresents the potential range of future outcomes possible under any combination of harvest policy and survey frequency. In the MSE (Appendix A), we identify several factors that may lead to incorrect assumptions in the stock assessment model.

The JTC recommends continuing work on the MSE by expanding the operating model to investigate the performance of a suite of assessment models with more complicated hypotheses about actual Pacific hake life-history and fishery dynamics. Furthermore, the JTC would like to continue the involvement of the JMC, SRG, and AP to further refine management objectives, as well as, determine scenarios of interest, management actions to investigate, and hypotheses to simulate.

Forecast decision table

A decision table showing predicted status and fishing intensity relative to target fishing intensity is presented with uncertainty represented from within the base-case model. The decision table (split into Tables g.1 and g.2) is organized such that the projected outcomes for each potential catch level (rows) can be evaluated across the quantiles (columns) of the posterior distribution. The first table (g.1) shows projected depletion outcomes, and the second (g.2) shows projected fishing intensity outcomes relative to the target fishing intensity (based on SPR; see table legend). Fishing intensity exceeding 100% indicates fishing in excess of the $F_{40\%}$ default harvest rate.

An additional table is presented containing a set of management metrics that were identified as important to the Joint Management Committee (JMC) and the Advisory Panel (AP) in 2012. These metrics summarize the probability of various outcomes from the base case model given each potential management action. Although not linear, probabilities can be interpolated from this table for intermediate catch values. Figure i shows the depletion trajectory through 2015 for several of these management actions.

The median spawning stock biomass is projected to remain constant with a 2013 catch of 650,000 mt, which is greater than the catch determined using the default harvest rate (626,364 mt). A catch of approximately 603,000 mt results in an equal probability of the stock increasing or decreasing from 2013 to 2014, based on individual trajectories from samples of the posterior distribution. The median values show slightly different results than the individual trajectories, which is not unexpected. Catches of less than 600,000 mt result in a slight increase in the median 2014 spawning biomass. However, the posterior distribution is highly uncertain, and either increasing or decreasing trends are possible over a broad range of 2012 catch levels. A 2013 catch of 696,000 mt results in the same projected catch of 696,000 mt in 2014 when applying the default harvest policy ($F_{40\%}$ – 40:10).

Table g.3 shows the same catch alternatives for 2013 and probabilities based on individual samples from the posterior distribution. The probability that the spawning stock biomass in 2014 remains above the 2013 level is 50% with a catch of 603,000 mt, the probability that the fishing intensity is above target in 2013 is 50% with a catch of 626,364 mt, and the probability that the predicted 2014 catch target is the same as a set value in 2013 is 50% for a set value of 696,000 mt in 2013. There is less than a 12% probability that the spawning stock will drop below 40% in 2014 for all catch levels considered.

Until cohorts are five or six years old, the model's ability to resolve cohort strength is poor. For many of the recent above average cohorts (2005, 2006, and 2008), the size of the year class was overestimated when it was age 2, compared to updated estimates as the cohort aged and more observations were available from the fishery and survey. Given this trend, a very uncertain 2010 year class, and a projected 2013 catch target that is both more than 1.5 times the highest catch in the time series and 1.75 times the median MSY, additional forecast decision tables were created given three states of nature about the size of the 2010 year class. These states of nature are low 2010 recruitment, medium 2010 recruitment, and high 2010 recruitment, and each state of nature is defined to have a probability of 10%, 80%, and 10%, respectively. Table g.4 shows the median depletion and fishing intensity within each state of nature, and it can be seen that in the low-recruitment state of nature the fishing intensity would be at target with a 2013 catch between 300,000 and 350,000 mt. Table g.5 shows the probability metrics for each state of nature. In the low-recruitment state of nature there is an equal probability that the spawning biomass in 2014 will be less than or greater than the spawning biomass in 2013 with a catch between 300,000 and 350,000 mt. There is an equal probability that the spawning biomass will be below 40% of unfished equilibrium spawning biomass with a catch near 400,000 mt.

Table g.1. Posterior distribution quantiles for forecasts of Pacific hake relative depletion (at the beginning of the year before fishing takes place) from the base model. Catch alternatives are based on: 1) arbitrary constant catch levels (rows a–g), 2) the catch level that results in an equal probability of the population increasing or decreasing from 2013 to 2014 (row h), 3) the median values estimated via the default harvest policy ($F_{40\%}$ – 40:10) for the base case (row i), 4) the catch level that results in the median spawning biomass to remain unchanged from 2013 to 2014 (row j), and 5) the catch level that results in a 50% probability that the median projected catch will remain the same in 2014 (row k).

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Beginning of year depletion**				
	Year	Catch (mt)					
a	2013	0	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	0	47.7%	68.3%	88.1%	114.4%	169.8%
b	2013	250,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	250,000	41.8%	62.5%	82.1%	108.8%	163.2%
c	2013	300,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	300,000	40.5%	61.5%	81.1%	107.7%	162.1%
d	2013	350,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	350,000	39.3%	60.3%	79.9%	106.6%	161.0%
e	2013	400,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	400,000	38.3%	59.2%	78.6%	105.6%	159.7%
f	2013	450,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	450,000	37.0%	58.0%	77.3%	104.4%	158.7%
g	2013	500,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	500,000	35.8%	56.8%	76.0%	103.2%	157.7%
h	2013	603,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	603,000	33.9%	54.3%	73.5%	100.7%	155.7%
i	2013	626,364	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	715,041	33.4%	53.8%	72.9%	100.2%	155.3%
j	2013	650,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	650,000	32.8%	53.2%	72.4%	99.7%	154.8%
k	2013	696,000	39.2%	56.9%	72.3%	95.4%	143.2%
	2014	696,000	31.7%	52.1%	71.3%	98.7%	153.9%

Table g.2. Posterior distribution quantiles for forecasts of Pacific hake fishing intensity (spawning potential ratio; (1-SPR)/(1-SPR$_{40\%}$); values greater than 100% denote fishing in excess of the $F_{40\%}$ default harvest rate) from the base model. Catch alternatives are explained in Table g.1.

Within model quantile			5%	25%	50%	75%	95%
Management Action			**Fishing Intensity**				
	Year	Catch (mt)					
a	2013	0	0%	0%	0%	0%	0%
	2014	0	0%	0%	0%	0%	0%
b	2013	250,000	37%	50%	63%	75%	91%
	2014	250,000	29%	42%	53%	64%	82%
c	2013	300,000	42%	57%	70%	82%	98%
	2014	300,000	34%	48%	61%	72%	90%
d	2013	350,000	47%	63%	76%	88%	105%
	2014	350,000	38%	54%	67%	80%	98%
e	2013	400,000	52%	68%	82%	94%	110%
	2014	400,000	42%	59%	74%	86%	104%
f	2013	450,000	57%	73%	87%	98%	114%
	2014	450,000	47%	64%	79%	92%	110%
g	2013	500,000	61%	77%	91%	102%	117%
	2014	500,000	50%	69%	84%	97%	115%
h	2013	603,000	68%	85%	99%	109%	123%
	2014	603,000	58%	78%	93%	106%	123%
i	2013	626,364	69%	87%	100%	111%	124%
	2014	715,041	65%	85%	100%	112%	129%
j	2013	650,000	71%	88%	101%	112%	125%
	2014	650,000	61%	81%	97%	109%	127%
k	2013	696,000	74%	91%	104%	114%	127%
	2014	696,000	64%	84%	100%	113%	129%

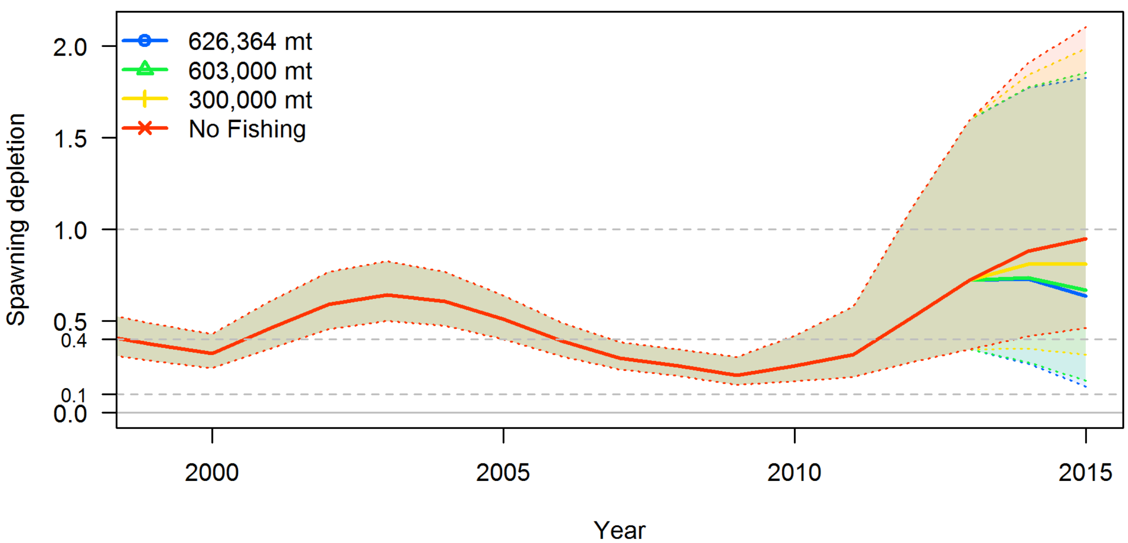

Figure i. Time-series of estimated spawning depletion to 2013 from the base-case model, and forecast trajectories to 2015 for several several management options from the decision table, with 95% posterior credibility intervals. The 2013 catch of 626,364 mt was calculated using the default harvest policy, as defined in the Agreement, which updates future catches (see Table g.1).

Table g.3. Probabilities of various management metrics given different catch alternatives. Catch alternatives are explained in Table g.1.

Catch	Probability $SB_{2014}<SB_{2013}$	Probability $SB_{2014}<SB_{40\%}$	Probability $SB_{2014}<SB_{25\%}$	Probability $SB_{2014}<SB_{10\%}$	Probability Fishing intensity in 2013 > 40% Target	Probability 2014 Catch Target < 2013 Catch
0	0%	2%	0%	0%	0%	0%
250,000	2%	4%	0%	0%	2%	1%
300,000	6%	5%	1%	0%	4%	2%
350,000	11%	6%	1%	0%	9%	4%
400,000	18%	6%	1%	0%	15%	9%
450,000	25%	7%	1%	0%	22%	14%
500,000	33%	8%	1%	0%	30%	20%
603,000	50%	9%	2%	0%	45%	36%
626,364	53%	10%	2%	0%	50%	39%
650,000	57%	10%	2%	0%	55%	42%
696,000	62%	11%	3%	0%	59%	50%

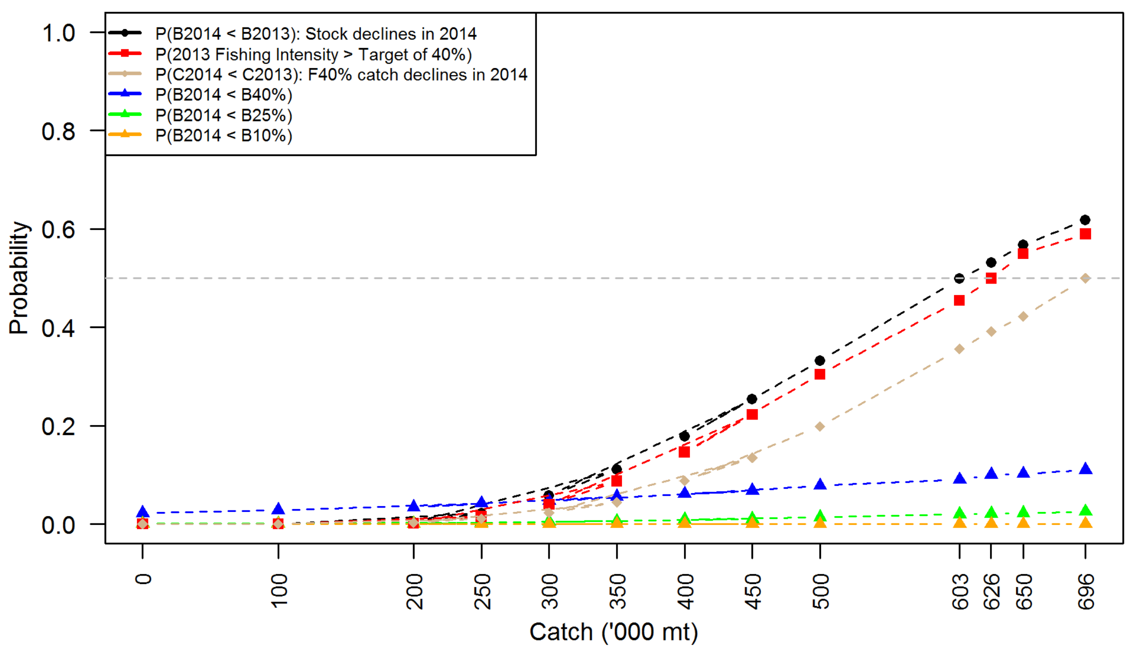

Figure j: Probabilities of various management metrics given different catch alternatives as defined in Table g.3. The points show these specific catch levels and lines interpolate between the points.

Table g.4. Median forecasts of Pacific hake depletion and fishing intensity (FI) for three different states of nature based on 2010 recruitment: 1) Low 2010 recruitment uses the lowest 10% of 2010 recruitment estimates, 2) Mid 2010 recruitment uses the middle 80% of 2010 recruitment estimates, and 3) High 2010 recruitment uses the highest 10% of 2010 recruitment estimates. Catch alternatives are explained in Table g.1.

	State Probability	Low 2010 recruitment 10%		Mid 2010 recruitment 80%		High 2010 recruitment 10%	
Year	Catch	Depletion	FI	Depletion	FI	Depletion	FI
2013	0	41.1%	0%	72.4%	0%	141.0%	0%
2014	0	49.3%	0%	88.2%	0%	165.8%	0%
2013	250,000	41.1%	91%	72.4%	63%	141.0%	37%
2014	250,000	43.9%	82%	82.2%	53%	160.3%	29%
2013	300,000	41.1%	98%	72.4%	70%	141.0%	42%
2014	300,000	42.8%	90%	81.1%	61%	159.3%	34%
2013	350,000	41.1%	104%	72.4%	76%	141.0%	47%
2014	350,000	41.6%	98%	79.9%	67%	158.3%	38%
2013	400,000	41.1%	109%	72.4%	82%	141.0%	52%
2014	400,000	40.3%	104%	78.6%	73%	157.2%	42%
2013	450,000	41.1%	113%	72.4%	87%	141.0%	57%
2014	450,000	39.0%	110%	77.3%	79%	156.2%	47%
2013	500,000	41.1%	117%	72.4%	91%	141.0%	61%
2014	500,000	37.6%	115%	76.0%	84%	155.1%	51%
2013	603,000	41.1%	123%	72.4%	98%	141.0%	68%
2014	603,000	35.1%	123%	73.5%	93%	153.0%	58%
2013	626,364	41.1%	124%	72.4%	100%	141.0%	69%
2014	626,364	34.6%	128%	73.0%	100%	152.5%	65%
2013	650,000	41.1%	125%	72.4%	101%	141.0%	71%
2014	650,000	34.0%	126%	72.4%	97%	152.0%	61%
2013	696,000	41.1%	127%	72.4%	104%	141.0%	74%
2014	696,000	32.9%	129%	71.3%	100%	151.0%	64%

Table g.5. Probabilities of various management metrics given different catch alternatives for three different states of nature based on 2010 recruitment: 1) the lower 10% of 2010 recruitment estimates, 2) the middle 80% of 2010 recruitment estimates, and 3) the highest 10% of 2010 recruitment estimates.. Catch alternatives are explained in Table g.1.

Catch	Probability $SB_{2014}<SB_{2013}$	Probability $SB_{2014}<SB_{40\%}$	Probability $SB_{2014}<SB_{25\%}$	Probability $SB_{2014}<SB_{10\%}$	Probability Fishing intensity in 2013 > 40% Target	Probability 2014 Catch Target < 2013 Catch
Lower 10% of 2010 recruitment						
0	0%	21%	1%	0%	0%	0%
250,000	16%	34%	3%	0%	15%	11%
300,000	31%	39%	5%	0%	40%	23%
350,000	56%	46%	6%	0%	74%	42%
400,000	65%	49%	9%	0%	93%	74%
450,000	69%	54%	10%	0%	99%	90%
500,000	77%	59%	14%	0%	100%	97%
603,000	89%	64%	20%	0%	100%	100%
626,364	91%	68%	20%	0%	100%	100%
650,000	92%	68%	21%	0%	100%	100%
696,000	93%	71%	24%	0%	100%	100%
Middle 80% of 2010 recruitment						
0	0%	0%	0%	0%	0%	0%
250,000	1%	1%	0%	0%	0%	0%
300,000	3%	1%	0%	0%	0%	0%
350,000	7%	1%	0%	0%	2%	0%
400,000	14%	2%	0%	0%	7%	2%
450,000	23%	2%	0%	0%	15%	6%
500,000	32%	2%	0%	0%	26%	13%
603,000	51%	3%	0%	0%	44%	32%
626,364	55%	4%	0%	0%	50%	36%
650,000	59%	4%	0%	0%	56%	40%
696,000	65%	5%	0%	0%	61%	50%
Upper 10% of 2010 recruitment						
0	0%	0%	0%	0%	0%	0%
250,000	0%	0%	0%	0%	0%	0%
300,000	0%	0%	0%	0%	0%	0%
350,000	0%	0%	0%	0%	0%	0%
400,000	0%	0%	0%	0%	0%	0%
450,000	0%	0%	0%	0%	0%	0%
500,000	0%	0%	0%	0%	0%	0%
603,000	0%	0%	0%	0%	0%	0%
626,364	1%	0%	0%	0%	0%	0%
650,000	2%	0%	0%	0%	0%	0%
696,000	3%	0%	0%	0%	0%	0%

Research and data needs

There are many areas of research that could improve stock assessment efforts, however we focus here on those efforts that might appreciably reduce the uncertainty (both perceived and unknown) in short-term forecasts of Pacific hake for management decision-making. This list is in prioritized order:

1. Continue development of the management strategy evaluation (MSE) tools to evaluate major sources of uncertainty relating to data, model structure and the harvest policy for this fishery and compare potential methods to address them. Work with the JMC, SRG, and AP to develop scenarios to investigate, management performance metrics to evaluate the scenarios, and hypotheses related to the life-history, fishery, spatial dynamics, and management of Pacific hake.

2. Review the proposed design of the joint hake/sardine (SaKe) acoustic survey to determine whether an optimized survey design could satisfy the needs of management for both Pacific hake and sardines. Included in this review should be a list of necessities that must be met to provide a consistent, accurate, and useful survey for Pacific hake.

3. Continue to explore alternative indices for juvenile or young (0 and/or 1 year old) Pacific hake. Initially, the MSE should be used to investigate whether an age-0 or -1 index could reduce stock assessment and management uncertainty enough to improve overall management performance.

4. Analyze recently collected maturity samples and explore ways to include new data in the assessment.

5. Routinely collect and analyze life-history data, including maturity and fecundity for Pacific hake. Explore possible relationships among these life history traits as well as with body growth and population density. Currently available information is limited and outdated.

6. Conduct research to improve the acoustic survey estimates of age and abundance. This includes, but is not limited to, species identification, target verification, target strength and alternative technologies to assist in the survey, as well as improved and more efficient analysis methods.

7. Conduct an annual acoustic survey if the necessary research to continue advancing acoustic survey techniques is not compromised (e.g., see item 6 above).

8. Apply bootstrapping methods to the acoustic survey time-series in order to bring more of the relevant components into the variance calculations. These factors include the target strength relationship, subjective scoring of echograms, thresholding methods, the species-mix and demographic estimates used to interpret the acoustic backscatter, and others.

9. Continue to explore process-based assessment modeling methods that may be able to use the large quantity of length observations to reduce model uncertainty and better propagate life-history variability into future projections.

10. Evaluate the quantity and quality of historical biological data (prior to 1988 from the Canadian fishery, and prior to 1975 from the U.S. fishery) for use in developing age-composition data.

11. Conduct further exploration of ageing imprecision and the effects of large cohorts via simulation and blind source age-reading of samples with differing underlying age distributions – with and without dominant year classes.

12. Investigate meta-analytic methods for developing a prior on degree of recruitment variability (σ_r), and for refining existing priors for natural mortality (M) and steepness of the stock-recruitment relationship (h).

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